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Report 5e

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The Hydrogeology of the IFYGL Moira River, Wilton Creek and Thousand Islands Study Areas





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✓✓ WATER RESOURCES
3 REPORT 5e

The Hydrogeology of the IFYGL Moira River, Wilton Creek and Thousand Islands Study Areas

By
R. C. Ostry and S. N. Singer

✓✓ MINISTRY OF THE ENVIRONMENT
Water Resources Branch

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PREFACE

Part of the contribution of the Ontario Ministry of the Environment to the International Field Year for the Great Lakes (IFYGL) program was the estimation of ground-water inflow to Lake Ontario from the Canadian side, by extrapolating data from selected areas representative of larger hydrogeologic regions. This report, which describes the hydrogeology of the IFYGL Moira River, Wilton Creek and Thousand Islands study areas is one in a series of reports dealing with the ground-water regimes of seven such selected representative areas along the Canadian shore of Lake Ontario.

D.N. Jeffs, Director
Water Resources Branch

Toronto, January , 1981

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(in back pocket)

Map

1. Physiographic regions, meteorologic stations and observation wells
2. Bedrock geology and topography
3. Location of water wells
4. Surficial geology
5. Potentiometric surface

ENGLISH - METRIC (SI) FACTORS

<u>to convert</u>	<u>to</u>	<u>multiply by</u>
inches (in)	centimetres (cm)	2.540
feet (ft)	metres (m)	0.305
miles (mi)	kilometres (km)	1.609
square miles (mi ²)	square kilometres (km ²)	2.590
cubic feet/second (cfs)	litres/second (l/s)	28.316
Imperial gallons (Ig)	litres (l)	4.546
Imperial gallons/day (Igp _d)	litres/second (l/s)	5.262×10^{-5}
Imperial gallons/day/ft ² (Igp _d /ft ²)	metres/second (m/s)	5.663×10^{-7}
Imperial gallons/day/ft (Igp _d /ft)	square metres/second (m ² /s)	1.726×10^{-7}
Imperial gallons/min (Igpm)	litres/sec (l/s)	.0758

ABSTRACT

The assessment of the ground-water contribution to Lake Ontario from the hydrogeologic region along the north shore of the Lake, extending eastward from the Trent River to the eastern boundary of the Lake Ontario drainage basin on the north shore of the St. Lawrence River, was undertaken by the Ontario Ministry of the Environment as part of its contribution to the International Field Year for the Great Lakes (IFYGL) program. Data were extrapolated from the hydrogeologic evaluation of the IFYGL Moira River, Wilton Creek and Thousand Islands study areas which were considered to be representative of the ground-water regime in this hydrogeologic region.

Field investigations of the geology, data from water-well records on file with the Ontario Ministry of the Environment and published literature were utilized for the assessment of the hydrogeology in the study areas.

Ground-water supplies are obtained from the upper part of the bedrock and from the overlying Wisconsinan drift. The bedrock consists of crystalline rocks of Precambrian age overlain by clastic rocks of Cambrian and Middle Ordovician age which are in turn overlain by marine carbonates of Middle Ordovician age. Well-productivity data suggest that the yield of bedrock wells is independent of the lithology and is primarily dependent on the fracture density in the bedrock. Water wells completed in the overburden are more productive than wells completed in the bedrock.

An overall decrease in the storage of the ground-water reservoir occurred in the hydrogeologic region during the Field Year period (April 1, 1972 to March 31, 1973) as identified by the decline of water levels ranging from 0.18 to 0.97 feet. This decrease in storage occurred although an increase in precipitation, ranging from 3.67 to 6.47 inches, was recorded over the long-term, annual average for the study areas.

Hydraulic conductivity values, derived from transmissivity estimates obtained from short-term pumping tests, were assigned to the various materials in the study areas. From these values it was estimated that a grand total of about 44 cubic feet per second of ground water is discharging directly into Lake Ontario along the shore of this hydrogeologic region.

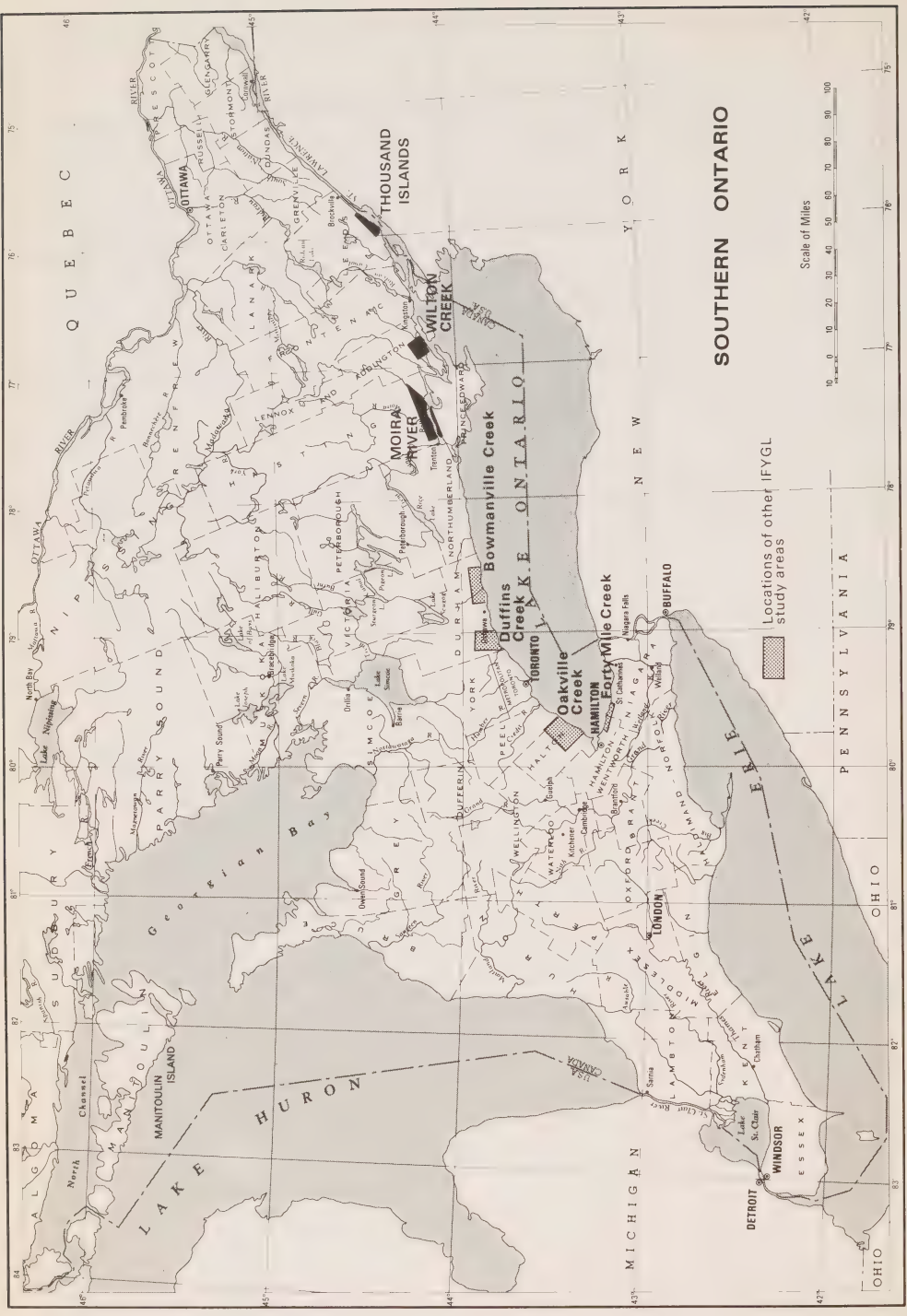


Figure 1. Locations of the IFYGL Moira River, Wilton Creek and Thousand Islands study areas in southern Ontario.

INTRODUCTION

PURPOSE AND SCOPE

Under the sponsorship of the Canadian and U.S. National committees for the International Hydrological Decade (IHD) program, the International Field Year for the Great Lakes (IFYGL) program was established to study the various hydrologic aspects of Lake Ontario and its drainage basin. Part of the Ontario Ministry of the Environment's contribution to the IFYGL program was the study of ground-water inflow to Lake Ontario, by extrapolating data from selected areas representative of larger hydrogeologic regions.

The ground-water regime developed in any region is a result of the geology, topography, drainage and climate of that area. The eastern part of the Lake Ontario drainage basin, from the Trent River to the eastern boundary of the basin on the St. Lawrence River, is considered to be a hydrogeologic region where ground-water conditions are generally uniform. In this region, proceeding eastward from the Trent River, the Moira River, Wilton Creek and Thousand Islands study areas are situated on the north shore of the lake.

For the purposes of the IFYGL study, to determine the amount of ground-water inflow to Lake Ontario, only the area adjacent to the lake was studied. Field investigations were made of the geology and test drilling was undertaken to provide information on aquifer characteristics, subsurface geology and ground-water levels in the area. Other aspects of the hydrogeologic assessment utilized information obtained from published literature and water-well records on file with the Ministry.

LOCATION

The Moira River IFYGL study area is located along the north and south shores of the Bay of Quinte in the counties of Hastings and Prince Edward; and extends eastward from the Trent River for approximately 17 miles to the Salmon River (Figure 1). The study area extends northward for approximately three and one-half miles inland from the Bay of Quinte in the County of Hastings and approximately one-half mile south of the Bay in the County of Prince Edward. The Moira River enters the study area from the north at approximately latitude $44^{\circ} 13' \text{ N.}$ and longitude $77^{\circ} 23' \text{ W.}$ and then flows southward, draining into the Bay of Quinte at latitude $44^{\circ} 09' \text{ N.}$

The Wilton Creek IFYGL study area is located on the north shore of Lake Ontario, 14 miles west of the City of Kingston, in the County of Lennox and Addington (Figure 1). This study area is bounded on the south by Lake Ontario between longitudes $76^{\circ} 45' \text{ W.}$ and $76^{\circ} 53' \text{ W.}$, a distance of approximately six miles, and extends inland (northwest) from the Lake for a distance of approximately six miles. Wilton Creek enters the study area from the northeast at latitude $44^{\circ} 15' \text{ N.}$ and longitude $76^{\circ} 49' \text{ W.}$ and flows southwestward across the study area to drain into Hay Bay at latitude $44^{\circ} 11' \text{ N.}$ and longitude $76^{\circ} 56' \text{ W.}$

The Thousand Islands IFYGL study area is located along the north shore of the St. Lawrence River, 10 miles east of the City of Brockville in the United Counties of Leeds and Grenville. The study area extends approximately two miles inland from the St. Lawrence River and for a distance of 12 miles along the shore between Bucks Bay and Patterson Bay at longitudes $75^{\circ} 59' \text{ W.}$ and $75^{\circ} 49' \text{ W.}$, respectively.

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Appreciation is also expressed to the residents of the area who permitted the use of abandoned wells on their properties to be used as observation wells.

GEOGRAPHY

PHYSIOGRAPHY

Parts of three physiographic regions, the Napanee Plain, the Prince Edward Peninsula and the Leeds Knobs and Flats, as delineated by Chapman & Putnam (1966), are found in the three study areas (Map 1). The Moira River study area is comprised of the Napanee Plain on the north side of the Bay of Quinte and the Prince Edward Peninsula on the south side of the bay. The Napanee Plain comprises all of the Wilton Creek study area and the Thousand Islands study area is wholly in the Leeds Knobs and Flats physiographic region.

Napanee Plain

According to Chapman & Putnam (1966), the Napanee Plain is a flat to undulating plain of limestone which was scoured, scraped and stripped of any existing overburden by the glaciers during Pleistocene time. The soil is generally only a few inches deep over much of the physiographic region. Some thicker deposits of glacial till occur in the Moira River basin, including a few scattered, long and thin drumlins. The low areas in both the Moira River and Wilton Creek study areas are often found to be covered with a shallow veneer of stratified clay (Chapman and Putnam, 1966).

Prince Edward Peninsula

The Prince Edward Peninsula is the extension of the Napanee Plain across the Bay of Quinte, projecting into the eastern part of Lake Ontario. Similarly, low areas within the study area are mantled by a thin cover of stratified clay.

Leeds Knobs and Flats

The Thousand Islands study area is wholly enclosed by this physiographic region and consists of knobs of Precambrian rocks separated by flat lands of glacial drift (Chapman & Putnam, 1966). The flat lands are the result of glacial scour along zones of least resistance in the bedrock where glacial debris and other sediments were subsequently deposited. The rock knobs are generally bare as a result of wave action from the Champlain Sea which removed some of the shallow drift cover during the close of glaciation on the North American continent. A thin veneer of clay, deposited by the Champlain Sea, is usually found levelling the low areas between the Precambrian outcrops.

TOPOGRAPHIC GRADIENTS AND RELIEF

In the Moira River study area the regional topographic gradient is in the order of 33 feet per mile (0.0065 feet per foot) on the north side of the Bay of Quinte. In the vicinity of the south shore of the Bay of Quinte (County of Prince Edward) the average topographic gradient is in the order of 75 feet per mile (0.0142 feet per foot). Maximum relief is approximately 150 feet as measured from lake level at 245 feet above sea level (asl) to high land at 400 feet asl near the northern and southern boundaries of the study area on either side of the Bay of Quinte.

In the Wilton Creek study area the regional topographic gradient is in the order of 33 feet per mile (0.0065 feet per foot) towards Lake Ontario. In the northwestern part of the study area the average slope of the land is southwestward to Hay Bay at approximately 20 feet per mile (0.0037 feet per foot). Maximum relief is approximately 150 feet as measured from Lake Ontario at 245 feet asl to the tops of rock ridges in the north part of the study area at 400 feet asl.

The regional topographic gradient in the Thousand Islands study area is in the order of 40 feet per mile (0.0075 feet per foot) towards the St. Lawrence River in the south east. Locally, topographic gradients in the vicinity of the St. Lawrence River are in the order of 200 feet per mile (0.0378 feet per foot) as a result of the bedrock-outcrop pattern in the study area.

DRAINAGE

Drainage of the study areas is a result of the physiography where the regional slope of the land is towards the Bay of Quinte, Lake Ontario and the St. Lawrence River. With the exception of Prince Edward Peninsula, the major streams in the hydrogeologic region drain southward, generally having their headwaters in the Precambrian Shield to the north. South of the Bay of Quinte, most streams drain to the north from the limestone highlands in the central portion of the Prince Edward Peninsula.

Moira River Study Area

Although the Moira River study area is part of the physiographic region of the Napanee Plain, drainage patterns in this area are different from the rest of the Napanee Plain to the east. In the Napanee Plain the dominant southwest direction of streamflow results from preferred glacial scour of the fracture or jointing pattern developed in the bedrock. Structural control from the bedrock is no longer dominant in the Moira River study area as evidenced by the southward-flowing pattern of creeks including the Moira River. This change can probably be attributed to the accumulation of glacial debris which is relatively thin but sufficient to alter the drainage pattern in this part of the study area. The prominent south-

west direction of drainage, that is typical of the rest of the Napanee Plain, is present in the physiographic region of the Prince Edward Peninsula on the south side of the Bay of Quinte.

Wilton Creek Study Area

Drainage in the Wilton Creek study area can be divided into two parts: streams draining southeastward and directly into Lake Ontario in the south and streams draining southwestward into Hay Bay in the north part of the study area. Water from Hay Bay reaches Lake Ontario by way of Adolphus Reach which separates the physiographic regions of the Prince Edward Peninsula and the Napanee Plain.

The development of long and narrow drainage basins parallel to each other in the study area, as well as over most of the limestone terrain of the Napanee Plain, appears to be related to a fracture or jointing pattern developed in the bedrock. The prominent southwest direction of streamflow was probably enhanced by glacial scour resulting from glacial movement in that direction. The southwest-northeast trending shore of Lake Ontario in the study area is also probably a development of structural and glacial control. Direct drainage to the Lake along the Lake Ontario shore is approximately at right angles to the shore, suggesting that this drainage pattern (southeast) is a consequence of structural control in the underlying bedrock. The largest stream in the study area is Wilton Creek which flows southwestward across the northern part of the study area, parallel to the Lake Ontario shore. This creek, as well as all the others in the north part of the study area, empties into Hay Bay.

Thousand Islands Study Area

The Thousand Islands study area shows an example of Precambrian drainage where present-day streams flow in the low areas between ridges and knobs of bedrock. The primary trend of streams and their tributaries in the area is northeast-southwest, parallel to the St. Lawrence River and the inferred direction of glacial movement. Changes in the primary trend of stream direction generally occur at right angles and continue for short distances until the primary trend is re-established. The main streams eventually drain into the St. Lawrence River at places where the land surface is sufficiently subdued to permit a change in stream direction to allow drainage into the St. Lawrence. For example, the largest stream draining through the study area is La Rue Creek which empties into the St. Lawrence River at La Rue Mills. Most of the tributaries to the creek are either northeast or southwest flowing, parallel to the St. Lawrence River. In several places, the downstream portion of a tributary is parallel to the upstream portion of that tributary but flows in an opposite direction. This reversal of drainage suggests that drainage patterns in the area are influenced to a large degree by structural features associated with the Precambrian bedrock.

CLIMATE

Data from meteorologic stations (Map 1) in the vicinity of the study areas are assumed to indicate the climate of the respective areas. The normal monthly and annual precipitation and temperature values for three representative stations are shown in tables 1 and 2 below. These long-term data (minimum 23 years of record) indicate that the climate of the study areas (i.e. the entire hydrogeologic region) is relatively uniform. The climate of the hydrogeologic region appears to be slightly wetter towards the east as indicated by long-term, annual precipitation values of 33.86 inches at the Belleville meteorologic station (Moir River study area), 35.38 inches at the Kingston, Ontario Hydro station (14 miles east of the Wilton Creek study area) and 38.09 inches at the Brockville station (10 miles east of the Thousand Island study area). The long-term annual temperature of the region is a uniform 45°F., as indicated by the records shown in Table 2.

TABLE 1. LONG-TERM ANNUAL AND MEAN MONTHLY PRECIPITATION FROM THE BELLEVILLE, KINGSTON ONTARIO HYDRO AND BROCKVILLE METEOROLOGIC STATIONS IN THE IFYGL MOIRA RIVER, WILTON CREEK AND THOUSAND ISLANDS STUDY AREAS (after Environment Canada, 1971).

STATION	YEAR	JAN.	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	
Belleville (25 year record)	mean rain fall (inches)	26.75	0.92	1.01	1.42	2.45	3.24	2.35	2.86	2.89	2.72	2.75	2.62	1.52
	mean snow fall (inches)*	7.11	1.96	1.60	1.12	0.31	0.01	-	-	-	0.02	0.60	1.49	
	mean total (inches)	33.86	2.88	2.61	2.54	2.76	3.25	2.35	2.86	2.89	2.72	2.77	3.22	3.01
Kingston Ontario Hydro (23 year record)	mean rain- fall (inches)	28.47	1.00	1.04	1.47	2.70	3.05	2.61	2.78	3.16	3.03	2.89	3.05	1.69
	mean snow- fall (inches)*	6.91	1.99	1.51	1.05	0.16	-	-	-	-	0.01	0.01	0.54	1.64
	mean Total (inches)	35.38	2.99	2.55	2.52	2.86	3.05	2.61	2.78	3.16	3.04	2.90	3.59	3.33
Brockville (25 year record)	mean rain- fall (inches)	29.52	0.94	0.99	1.62	2.68	3.30	2.73	3.07	3.51	3.32	2.97	2.90	1.49
	mean snow- fall (inches)*	8.57	2.39	1.99	1.26	0.17	0.01	-	-	-	0.06	0.69	2.00	
	mean total (inches)	38.09	3.33	2.98	2.88	2.85	3.31	2.73	3.07	3.51	3.32	3.03	3.59	3.49

* water equivalent

[illegible]

GEOLOGY

BEDROCK GEOLOGY

General Stratigraphy

The Moira River and Wilton Creek study areas are underlain by Paleozoic rocks of Middle Ordovician age which have been described by Liberty (1960 and 1971). The rocks in the Thousand Islands study area are of Precambrian age and have been described by earlier workers, notably Wynne-Edwards (1962, 1963, 1967) and Hewitt (1963). Surface exposure of these rocks are found in creek valleys, in bedrock plains near Lake Ontario and in the bluffs along the Lake Ontario shore. Table 3, after Hewitt (1963) and Liberty (1960a, 1960b and 1971), indicates the stratigraphic sequence and includes a brief description of the lithology of the formations present in the study areas.

Precambrian Lithology

Rocks of Precambrian age outcrop in the Thousand Islands study area and are present at depth in the Moira River and Wilton Creek study areas. Since their deposition, the Precambrian rocks have been subjected to folding, faulting, metamorphism and other tectonic processes which have deformed the original sediments into a complex system of hard crystalline rocks.

The oldest rocks are the quartzites and gneisses of the Grenville Series whose distribution is shown in Map 2. These rocks were intruded by massive, dark-coloured gabbro, diorite and their altered equivalents (Buckingham Series) which outcrop in the north part of the Thousand Islands study area (Table 3). The Buckingham Series was in turn intruded by a series of granites and their respective gneisses (Table 3) which were later cut by dikes of diabase or porphyritic andesite. The complex structural and stratigraphic arrangement of the Precambrian rocks is beyond the scope of this report and further reference is made to investigations conducted by Wynne-Edwards (1962, 1963 and 1967).

In summary the complex history of the Precambrian sediments has resulted in extensive changes in their original character so that they now appear as a relatively-homogeneous series of hard, crystalline, and well-jointed rocks. For the purposes of this report, the Precambrian aged rocks are considered to represent a single stratigraphic unit.

Paleozoic Lithology and Depositional Environment

Overlying the Precambrian surface are Paleozoic sediments which form the bedrock surface in the Moira River and Wilton Creek study areas. The lithologies described in the composite stratigraphic sequence (Table 3) for the study areas suggests that during Cambrian and Early Ordovician times, the Precambrian Shield was inundated by shallow, westward transgressing seas in which sediments of sand and clay were deposited. These basinal deposits are a lithostratigraphic unit comprised of the Potsdam and Shadow Lake formations of the Basal Group (Liberty, 1969) and are in turn overlain by marine carbonate rocks; indicative of deepening water conditions during Middle Ordovician time.

TABLE 3. BEDROCK STRATIGRAPHY IN THE IFYGL MOIRA RIVER, WILTON CREEK AND THOUSAND ISLANDS STUDY AREAS (after Hewitt, 1963 and Liberty, 1971)

EON	ERA	SYSTEM	SERIES	GROUP	FORMATION	MEMBER	THICKNESS	LITHOLOGY
PHANEROZOIC	PALEOZOIC	ORDOVICIAN (MIDDLE)	MOHAWKIAN	SIMCOE	LINDSAY	Upper	300'	Calcareous claystone; grey, soft, semi-nodular, sublithographic.
						Lower		Limestone; blue, hard, very-finely crystalline, sublithographic.
					VERULAM		350'	Alternating thin-bedded limestone; hard, crystalline and calcareous claystone.
					BOB-CAYGEON	Upper	20' -45'	Calcarenite-limestone-claystone; brown, very-finely crystalline.
						Lower		Limestone; brown to grey, calcarenitic, sublithographic, argillaceous.
					GULL RIVER	D	140' -300'	Limestone; brown, lithographic to sublithographic.
						C		Limestone; grey, lithographic
						B		Limestone; grey, sublithographic argillaceous.
						A		Limestone-dolic limestone-dolomite; grey-brown, lithographic to crystalline.
				BASAL	SHADOW LAKE		0-50'	Shale, arkose and sandstone; red and green.
POTSDAM		0-150'	Quartz sandstone and siltstone; red, grey and yellow.					
PRECAMBRIAN	MIDDLE TO LATE PRECAMBRIAN (PROTEROZOIC)	CAMBRIAN	CROIXAN					Basic Intrusive Rocks; dikes of <u>diabase</u> and porphyritic <u>andesite</u> .
								Younger Plutonic Rocks; <u>granite</u> , <u>granite gneiss</u> and <u>granite pegmatite</u>
								Older Plutonic Rocks; <u>diorite</u> and <u>gabbro</u> .
								Metasediments; <u>quartzite</u> , <u>paragneiss</u> and <u>schist</u> .

The carbonate sequence of rocks (Simcoe Group) has been subdivided by Liberty (1960a, 1960b, and 1971) into the following formations in ascending order: Gull River, Bobcaygeon, Verulam and Lindsay.

The Simcoe Group, as defined by Liberty (1969), is a rock unit consisting of limestone with no significant natural break in the lithology of the carbonate sequence within that group. The term Bobcaygeon Formation was introduced by Liberty (1969) for a lithogenic unit that lies between the lithographic limestone of the Gull River Formation and the equally distinctive interbedded limestone and calcareous claystone of the Verulam Formation. The Lindsay Formation overlies the Verulam Formation and consists of the remaining limestone sequence of the Simcoe Group. The areal distribution of these Paleozoic sediments in the study areas is shown in Map 2.

The marine carbonates that comprise the Gull River, Bobcaygeon, Verulam and Lindsay formations indicate deepening conditions of the Middle Ordovician sea. Liberty (1969) suggests that the lithographic limestones of the Gull River Formation were formed from precipitated lime-mud. Shallowing conditions are indicated by the clastic nature (calcarenites) of the Bobcaygeon Formation. Fluctuating conditions of shallow and deeper water are indicated by the alternating limestone and claystone units of the Verulam Formation. The increase in calcareous material of the Lindsay Formation over the underlying Verulam Formation suggests slightly deeper and more stable conditions (Liberty, 1969) although fluctuating conditions are indicated by changes in sediment composition and the presence of rubbly materials.

Paleozoic Structure

The Paleozoic strata exhibit a gentle regional inclination that varies from 15 to 22 feet per mile to the south in the Moira River and Wilton Creek study areas (Liberty, 1960a; 1960b and 1971). The present attitudes of the strata are believed (Liberty, 1969) to be essentially those of their initial depositional dip. Higher dips from eight to 15 degrees occur and probably reflect the drape of the Paleozoic sediments over the underlying high areas (monadnocks) on the Precambrian surface (Liberty, 1971).

The Frontenac Axis is a ridge or platform of Precambrian rocks extending southeastward through the Thousand Islands study area and across the St. Lawrence River into the United States. The Paleozoic-Precambrian unconformity can be readily observed along the southwest flank of the Frontenac Axis (between the Thousand Islands and Wilton Creek study areas) where flat-lying sandstones of the Potsdam Formation unconformably overlie the Precambrian deposits. Locally, the absence of both the Potsdam and Shadow Lake formations in the Kingston area suggests that a local, Precambrian basement high existed during the Cambrian and into the Ordovician (i.e. non deposition) at this locality (Liberty, 1971).

The Peterborough Arch is a name proposed by Liberty (1969) for a broad Precambrian platform extending southeastward from the Lake Simcoe area through the Moira River study area into the County of Prince Edward. This broad feature separates the Cambrian sediments on the east side of the arch in the Kingston area (Potsdam Formation) from those on the west side in the Trenton to Toronto area. Liberty (1969) also indicates that the Middle Ordovician carbonate sequence thickens southward, east of the arch. Several disconformities have been delineated by Liberty (1963, 1971) in these Middle Ordovician strata that are attributed to the presence of the arch at the time of deposition. These disconformities occur within the Gull River Formation, between the Gull River and Bobcaygeon formations and at the base of the Verulam Formation. The presence of this arch is considered to be the reason for the alternating conditions of deeper and shallow water in the Lindsay Formation (Liberty, 1969).

Faulting of the Paleozoic strata has been recognized in the study areas. Most faults exhibit small throws of two to ten feet (Liberty, 1971) although normal faults with 100 feet of throw have been recorded at Picton (Liberty, 1960b) and along the Salmon River (Liberty, 1963) in the Moira River study area (Map 1). This faulting is considered to be very recent in age for the most part.

Bedrock Topography

The elevation of the bedrock surface for the study areas is illustrated in Map 2. The attitude of this surface was obtained from records of water wells, on file with the Ministry of the Environment (Map 3), that penetrate the overburden to the bedrock. These data indicate that the bedrock surface is similar to that of the present-day topographic or land surface in all three study areas. A veneer of glacial debris is found capping the bedrock over parts of the areas but for the most part, bedrock outcrops are found very close to the land surface.

PLEISTOCENE GEOLOGY

The unconsolidated materials overlying the bedrock in the study areas were deposited during the Pleistocene or Glacial Epoch and are considered to be Wisconsinan in age. Investigations of these deposits have been made by earlier workers, notably Coleman (1936), Gillespie et al (1962), Gillespie et al (1963), Chapman and Putnam (1966), Henderson (1970), and Funk (1977).

These Pleistocene deposits are described as being a thin veneer of glacial, glaciofluvial and glaciolacustrine materials overlying the bedrock. The surface expression and areal extent of these deposits are shown in Map 4.

Only the latest events of the last glacial stage (Wisconsinan) are represented by the deposits found in the IFYGL study areas. This suggests that glacial erosion was probably dominant in the eastern part of the Lake Ontario basin during most of the Wisconsinan Stage. Ice advanced from the east, down the St. Lawrence River into the Lake Ontario basin scouring and modifying the bedrock in its path. Eventually the ice filled

the Ontario basin and spilled out on to the surrounding high land, merging with ice from lobes advancing from the north to form a vast continental ice sheet over Ontario. Several major glacial advances and subsequent retreats occurred during the Wisconsin Stage which lasted for approximately 100,000 years. The major events that occurred in the Great Lakes region have been documented by Dreimanis and Karrow (1972).

For the most part glacial till or rubble is found capping the bedrock. These deposits are generally less than 10 feet thick and are comprised of ground-up fragments of bedrock that vary from clay to gravel size. The till is generally described as being a stony sand till. Drumlins in the Wilton Creek study area indicate a southwesterly direction for ice movement whereas drumlins in the Moira River study area are oriented east-west, suggesting a westerly shift in the direction of ice movement.

Older deposits of sand and gravel of limited areal extent have been identified (Funk, 1977) below the till in the vicinity of Wilton Creek and appear to be glaciofluvial in origin. In the Thousand Islands study area, ice-contact deposits of sand and gravel have been delineated by Henderson (1970) and their extent also appears to be limited for the most part.

At the close of the Wisconsin glaciation, the ice front retreated to the east and north uncovering southern Ontario. The Ontario Lobe withdrew from the Lake Ontario basin and stood in the St. Lawrence Valley. Meltwaters were ponded around the periphery of the ice forming high-level glacial lakes. As the ice front retreated, lower outlets for the glacial lakes were uncovered and the levels of the lakes dropped accordingly. Wave action in the lakes modified the underlying till plain and glaciolacustrine deposits of clay filled the depressions in the till plain. In the Moira River study area, thin deposits of sand (Map 4) are found near the present-day shore of Lake Ontario in the eastern part of the study area and probably represent a water level slightly higher than the present lake (Coleman, 1936).

As the glacier receded, an arm of the sea, called the Champlain Sea, entered the St. Lawrence-Ottawa Lowland. The western limit of the sea is not precisely defined but is believed to have extended into the eastern part of the Lake Ontario basin. Chapman & Putnam (1966) suggest that the western shore of the Champlain Sea was on the rocky edge of the Precambrian Shield (Frontenac Axis) where conditions were not favourable for the formation of beaches. Deposits of marine clay and sand have been delineated by Henderson (1970) in the Thousand Islands study area. Some of the clay sediments in the Wilton Creek study area are believed to have been deposited by the Champlain Sea (Gillespie et al, 1963).

HYDROGEOLOGY

GROUND-WATER OCCURRENCE

Ground water is an aspect of the hydrologic cycle which has resulted from the infiltration of water at the earth's surface. The water has moved through the unsaturated zone into the saturated zone and, under the influence of gravity, to a point of natural or artificial discharge in a stream, lake or well. The water stored in the saturated zone is called ground water and natural recharge to this system generally occurs either directly from precipitation infiltrating into the ground or indirectly from snowmelt.

An aquifer is defined as a water-bearing horizon that will transmit significant amounts of water to a well. In the exploration for ground-water resources, the connotation of the wording "significant amounts" further defines the term aquifer with respect to the usage of water for domestic, industrial or municipal supplies. An aquifer in the context of this report is one that will supply water for limited domestic use. In the study areas, aquifers are found both within the overburden deposits and in the bedrock.

Ground water is stored in the interstices or openings or pore spaces comprising the material through which the ground water moves. The capacity of any material to hold or yield water is dependent on the porosity and permeability of the material (i.e. the total number of interstices or voids and the interconnection of these interstices, respectively). Thus, a high porosity material such as shale or clay will not yield large quantities of water due to absorption phenomena resulting from the molecular size and poor interconnection of the pore spaces.

Within the overburden, the most productive materials are the granular deposits of sand and gravel. These permeable materials, when encountered in the subsurface, are utilized as sources of ground water. These deposits, however, do not appear to be abundantly distributed in the study areas, as indicated from water-well records on file with the Ministry of the Environment and the surficial geology shown in Map 4.

Numerous bored and dug wells penetrating low water-yielding materials such as glacial deposits of till or glaciolacustrine silts and clays are also exploited to supply water for domestic needs. The yields from wells completed in the above-mentioned, low-yield materials, are essentially controlled by the storage capacity of the large-diameter wells. Recent studies in the prairies (Meyboom et al, 1966) suggest that the movement and storage of ground water in glacial tills and some clays is within joints or cracks developed in these materials.

The bedrock comprised of the marine carbonates of the Simcoe Group (Ordovician) and the crystalline rocks of the Precambrian, is generally a poor aquifer in the study areas. Microscopic examination indicates that the bedrock porosity is

low resulting from the past history of these rocks (compaction, consolidation, metamorphism, etc.) since their deposition. The rocks of the Cambro-Ordovician Basal Group (Potsdam and Shadow Lake formations) are better aquifers as a result of their granular nature. Although the primary porosity of these granular materials has been restricted by subsequent cementation of the grains, yields of water wells completed in these formations (Sobanski, 1970) are substantially better than those wells completed in the Ordovician limestones or the crystalline rocks of the Precambrian.

Secondary porosities consisting of joints, fractures, cleavage planes and faults were subsequently developed in the bedrock, probably as a result of tectonic processes. Other processes, such as those associated with weathering have enlarged these planes (including the original bedding planes), creating secondary voids through which the ground water presently flows. These secondary openings tend to become tighter and fewer in number with increasing depth.

GROUND-WATER LEVELS

Change in Storage

The change in storage of the ground-water reservoir can be identified by the measurement of rising and declining water levels in water wells or boreholes. During periods of high precipitation, storage in the ground-water reservoir is increased after the soil moisture deficiency (SMD) in the unsaturated zone is replenished. When the SMD is satisfied, the infiltrating water will percolate downwards into the saturated zone under the influence of gravity. Conversely, storage is decreased under conditions where the infiltrating water is intercepted before reaching the saturated zone while discharge from the saturated zone continues. These conditions occur during periods of low precipitation and/or excessive use of subsurface water by man or vegetation.

An observation-well network of private and abandoned wells was established for the IFYGL program in the Moira River, Wilton Creek and Thousand Islands study areas. The change in water levels was computed for the wells in these networks over the Field Year period, from April 1, 1972 to March 31, 1973 and the results are presented in Table 4.

The data in Table 4 suggest that an overall decrease in the storage of the ground-water reservoir occurred in all the IFYGL study areas during the Field Year. This is indicated by an average decline of 0.97, 0.18 and 0.28 feet of water levels measured in the observation-well networks for the Moira River, Wilton Creek and Thousand Islands study areas, respectively.

TABLE 4. STATIC WATER LEVELS AND CHANGE IN STORAGE OF OBSERVATION-WELL NETWORKS IN THE IFYGL MOIRA RIVER, WILTON CREEK AND THOUSAND ISLANDS STUDY AREAS

Area	Well	Diameter (inches)	Material	Depth (feet)	Static Level April 1/72 (feet)	Static Level March 31/73 (feet)	s (feet)	Average s (feet)
Moira River Study Area	BE-20	6½	LS*	16	10.60	9.46	+1.14	
	BE-13	6	LS	26	19.50E**	19.50	0.00	
	BE-17	6	LS	35	1.00	2.67	-1.67	
	BE-2	6½	LS	35	6.50E	7.76	-1.26	
	BE-9	6	LS	37	10.20E	10.29	-0.09	
	BE-8	6½	LS	40	11.40E	12.06	-0.66	
	BE-18	6½	LS	42	0.70E	1.32	-0.62	
	BE-12	6½	LS	52	2.00E	3.67	-1.67	
	BE-19	6½	LS	55	3.20E	0.85	-2.35	
	BE-10	6½	LS	56	5.00E	5.00	0.00	
	BE-15	6½	LS	61	4.60E	5.38	-0.78	
	BE-14	8	LS	63	3.23E	3.47	-0.24	
	BE-6	6½	LS	72	4.45E	6.86	-2.41	
	BE-11	6	LS	89	12.50E	13.14	-0.64	
	BE-3	10	LS	125	8.63E	15.52	-6.89	
	BE-16	6½	LS	127	9.14E	8.82	+0.32	-0.97
Wilton Creek Study Area	WI-2	6	LS	22	13.18E	11.44	+2.37	
	WC-7	6½	LS	23	8.79	11.31	-2.52	
	WC-3d	1½	LS	28	15.60E	14.42	+1.18	
	WI-1	6	LS	40	4.62E	5.06	-0.44	
	WC-4	6½	LS	44	4.02	6.00	-1.98	
	WC-3c	1½	LS	45	26.20E	25.90	+0.30	
	WC-5	6½	LS	103	4.35	6.45	-2.10	
	WC-36	1½	LS	116	30.00E	27.50	+2.50	
	WC-3a	1½	LS	177	26.70E	27.60	-0.90	-0.18
Thousand Island Study Area	TI-8	48	OB*	7	0.59E	1.65	-1.06	
	TI-5	48	OB	11	3.24E	3.78	-0.54	
	TI-9	48	OB	12	3.50E	3.99	-0.49	
	TI-11	48	OB	12	1.32E	2.53	-1.21	
	TI-3	48	OB	14	5.61E	5.83	-0.22	
	TI-10	48	OB	15	2.10E	2.24	-0.14	
	TI-12	48	OB	15	1.99E	2.79	-0.80	
	TI-4	6	PC*	24	3.00E	4.60	-1.60	
	TI-2	6	PC	35	14.10E	9.82	+4.28	
	TI-7	6	PC	45	1.80E	2.18	-0.38	
	TI-1	8	PC	60	7.46E	7.30	+0.16	
	TI-6	5	PC	61	3.12E	4.53	-1.41	-0.28

* : LS = Limestone, PC = Precambrian, OB = Overburden

** : E = Estimate

Climatological data, presented in Table 5, indicate that excess precipitation over the long-term average occurred in all the study areas during the Field Year. Long-term data are not available for the Morven IHD station and it was assumed that long-term data from the Kingston Ontario Hydro station (approximately 14 miles east of the Wilton Creek study area) were representative for the Wilton Creek study area. Other IFYGL studies to the west, in the Bowmanville-Newcastle area, Duffins, Oakville and Forty Mile creeks, indicate that excess precipitation over the long-term average contributes to a rise in ground-water levels. The decrease in ground-water levels that occurred during a period of excess precipitation in the Moira River, Wilton Creek and Thousand Islands study areas suggests that the present ground-water resources are being slowly depleted by the consumption of water from the existing wells in the study areas. It would appear that a prolonged decrease in precipitation from the long-term annual average will probably result in a shortage of ground-water supplies in these areas.

Observation-Well Hydrographs

Observation-well hydrographs at site WC-8 (Figure 2), in the Wilton Creek study area for the years 1968 to 1973, indicate that the maximum fluctuation of ground-water levels over this period of time is approximately six feet. Long-term hydrographs are not available for the Moira River and Thousand Islands study areas but a comparison of observation-well hydrographs from these areas over the Field Year period from April 1, 1972 to March 31, 1973 (Figure 3) indicates a similar response over that period. Maximum peaks and lows in the water-level stages occur at the same time in the study areas. The lowest depth of water level was recorded in the month of September with a peak in late December - early January and a minor low at the end of February (Figure 3). This annual cyclic phenomenon results from the change in the rate of recharge to the ground-water reservoir. Climatological data for the study areas indicate that the long-term monthly precipitation (Table 1) is relatively constant, ranging from $2\frac{1}{2}$ to $3\frac{1}{2}$ inches per month. During the growing season (May to October inclusive) a decline in water levels occurs, reflecting a soil-moisture deficiency (SMD) created in the unsaturated zone from the consumption of available water by vegetation and evaporation from the land surface. A corresponding rise in water levels occurs during the non-growing season (November to April inclusive) after the SMD in the unsaturated zone is replenished and recharge to the ground-water reservoir resumes. The low recorded in February is probably due to freezing of the land surface, consequently inhibiting recharge to the ground-water reservoir while discharge from the ground-water reservoir continues.

TABLE 5. AVERAGE ANNUAL PRECIPITATION IN THE IFYGL MOIRA RIVER, WILTON CREEK AND THOUSAND ISLANDS STUDY AREAS (from Environment Canada, 1971; 1972-1973).

Area	Station	Annual Precipitation 1/4/72 - 31/3/73 (inches)	Average Long-term, Annual Precipitation (inches)	Deviation from Long-term Annual Precipitation (inches)
Moir River	Belleville	37.82	33.86	+ 3.76
Wilton Creek	Kingston Ontario Hydro	N.A*	35.38	+ 6.47
	Morven IHD	41.85	N.A*	
Thousand Islands	Brockville	43.32	38.09	+ 5.23

NA* data not available

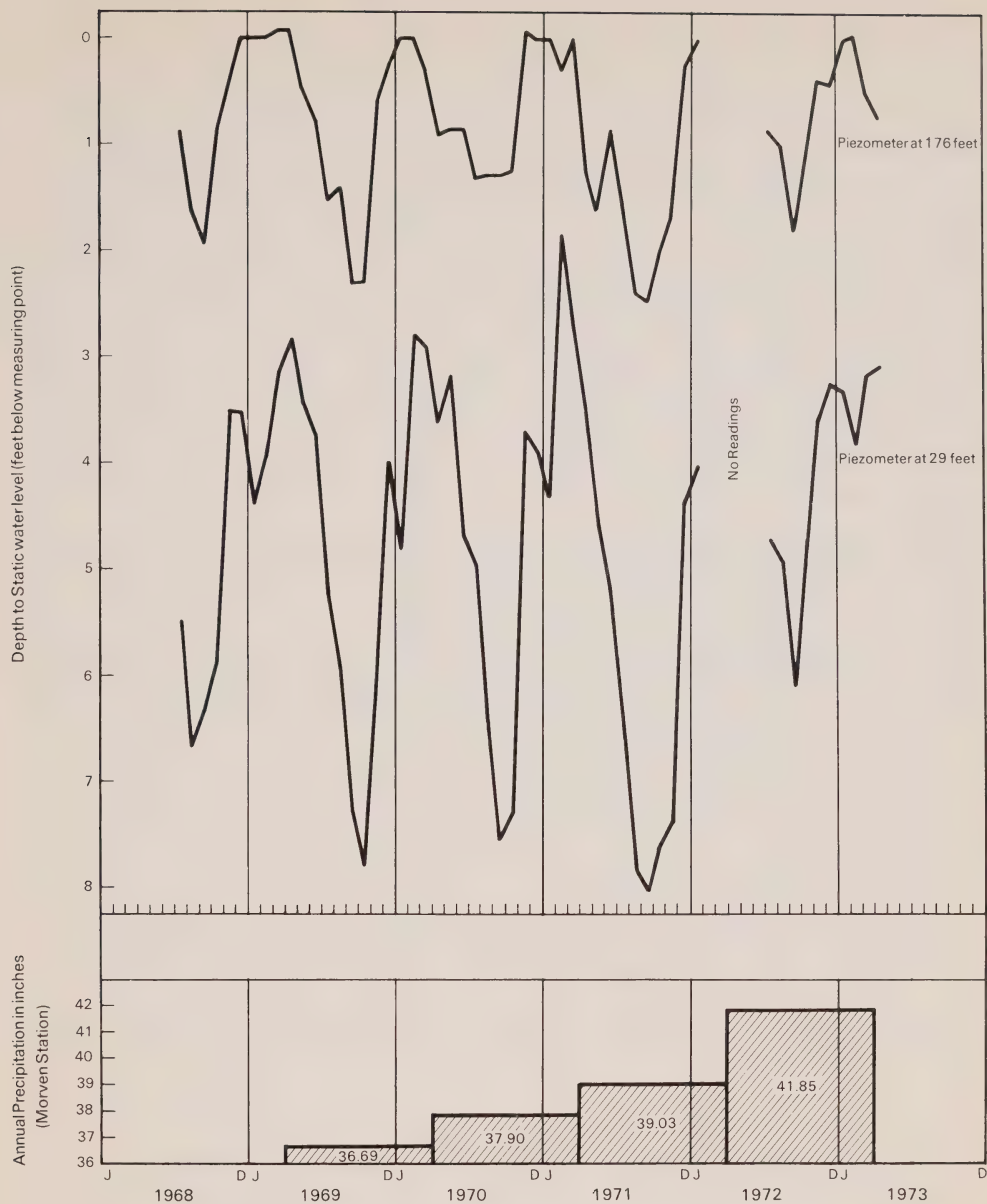


Figure 2. Observation-well hydrograph for site WC-8 in the IFYGL Wilton Creek study area (after Funk, 1977).

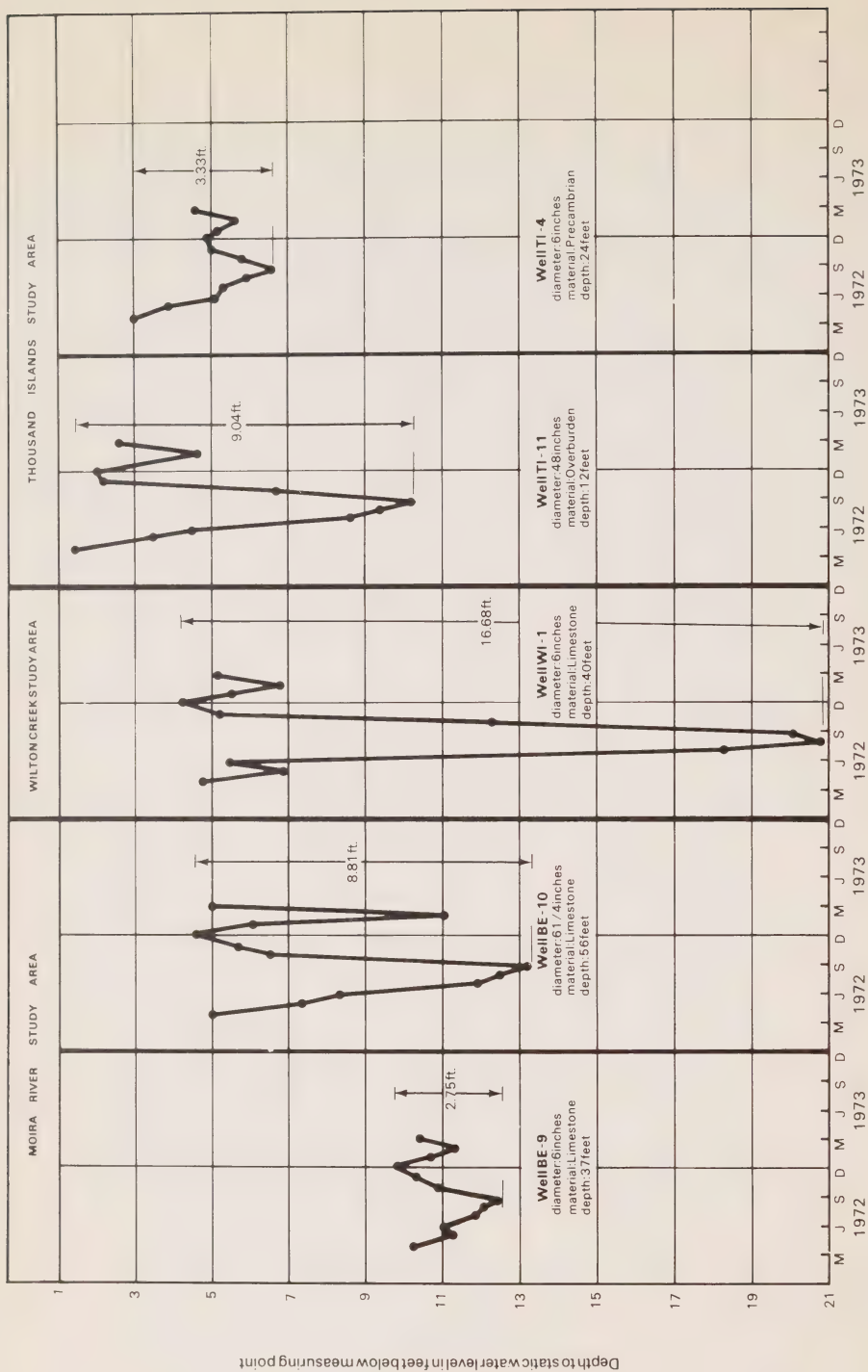


Figure 3. Observation - well hydrographs from the IFYGL Moira River, Wilton Creek and Thousand Islands study areas.

As indicated earlier, the primary source of ground water in the study areas is the bedrock which is generally found outcropping, or very close to the land surface. If it is assumed that recharge to the ground-water reservoir in the bedrock is constant, the magnitude of the ground-water level fluctuations can be used as a qualitative measure of the hydraulic properties. Large fluctuations in ground-water levels would represent limited storage capacity in the bedrock and conversely small fluctuations would represent large storage capacity. During the Field Year period an excess of precipitation, ranging from 3.76 to 6.47 inches over the long-term annual average (Table 5), was recorded as occurring in the three study areas. The response of the observation wells to this input was similar (Figure 3); however, the magnitude of the water-level fluctuations for the Field Year period ranged from 2.75 to 16.86 feet. This variability in magnitude suggests that significant differences in the hydraulic properties (i.e. storage capacity) of the materials are present (Figure 3), if it is assumed that a constant rate of recharge occurred over the study areas.

GROUND-WATER MOVEMENT

General

The ground-water flow field is a three dimensional field that occurs from the top of the saturated zone down to a depth where ground-water flow becomes impossible (i.e. where the material in the saturated zone becomes completely impermeable). The ground water at any point in this field can be expressed in terms of total head defined by Hubbert (1953) as the sum of pressure head, elevation head and velocity head at that point; however, the velocity head is so small for ground-water considerations, it can be neglected. The static water level (the level to which water rises) in a well is a measure of the ground-water head at the point where the water was found. The total flow vector (Meyboom et al, 1966) of the three-dimensional, ground-water field can be resolved into two, two-dimensional horizontal and vertical vectors. The "flow resultant" is the flow component of the ground water in the vertical plane and the "horizontal component" is the flow component of the ground-water in the horizontal plane (Meyboom et al, 1966). In either case, the component of flow that is depicted (flow resultant or horizontal component) is assumed to essentially represent the total flow vector of the ground-water flow field.

Water-Level Data

As indicated above, the static water levels in wells are a measure of the potential causing ground-water flow. Water-level data from water-well records on file with the Ministry of the Environment suggest that the static water level of any well, completed in any water-bearing horizon, is usually found within a few feet of the land surface, regardless of the season or year in which the well was drilled. An average value for depth to static water level was computed for 866, 205 and 282 bedrock wells in the Moira River, Wilton Creek and Thousand Islands study areas, respectively. The average, static

water-level value for wells in each of the above-mentioned study areas was found to be 11 feet (standard deviation of 8 feet), 14 feet (standard deviation of 9 feet) and 14 feet (standard deviation of 10 feet), respectively. Although these wells were drilled in different seasons and completed in different water-bearing horizons over a span of approximately 20 years, the average, static water level is within a few feet of the land surface. This feature can be observed in figures 2 and 3 where the maximum depth to the static water level occurred in September, 1972 during the Field Year period. The water-level depths were 13 feet in the Moira River study area, 21 feet in the Wilton Creek study area and 11 feet in the Thousand Islands study area. Anomalously deep water-levels can usually be traced to excessive withdrawals or consumption of ground-water or to deep wells completed in the less active or stagnant part of the ground-water reservoir. All of these data suggest that a hydraulic connection exists within the bedrock and that the general direction of ground-water flow can be determined from these water-level data.

Potentiometric Surface

The water-level data from water-well records in the study areas were used to compile a potentiometric surface map for ground water in the bedrock. A potentiometric map was not prepared for wells completed in the overburden as insufficient data were available. The hydraulic-head values (water-level elevations) for the overburden wells are shown separately on the map (Map 5) prepared for the bedrock. The similarity in the two sets of data, for the overburden and bedrock, suggests that they are hydraulically connected. For purposes of this report, the overburden and the uppermost part of the bedrock are considered to constitute the active part of the ground-water reservoir.

Lines of equal potential were interpolated between values of hydraulic head obtained from water-well records on file with the Ministry of the Environment (Map 5). By definition ground-water flow is at a direction normal to the lines of equal potential. Examination of Map 5 indicates that the potentiometric surface conforms to the topographic expression of the ground surface and may be considered to be a subdued replica of that surface. The ground-water divides appear to be generally coincident with the surface-water divides and by analogy, areas of recharge and discharge are topographic highs and lows, respectively. Thus, ground-water flow in a lateral direction is controlled by the topography; movement being from topographically high to topographically low areas.

Hydraulic Gradient

Assuming that the "horizontal component" of ground-water flow (as illustrated in Map 5) represents the total flow vector of the ground-water flow field, the slope of the potentiometric surface is the hydraulic gradient (I) under which ground-water movement occurs. Ground-water movement is dependent on the hydraulic gradient (I) according to

Darcy's Law, $Q = KIA$, where:

Q = Quantity of flow per unit time

K = Hydraulic conductivity

I = Hydraulic gradient

A = Cross-sectional area through which movement takes place.

The hydraulic gradient (I) is the head loss (in feet of water) per unit distance (foot) of flow path, resulting from the frictional resistance to flow within the voids of the material through which the ground water moves.

As indicated earlier, the potentiometric surface (Map 5) is similar to the land surface and ground-water flow is from high to low potential in a direction normal to the lines of equal potential. The hydraulic gradient (I) is in the order of 0.0065 feet per foot in the Moira River and Wilton Creek study areas and 0.0075 feet per foot in the Thousand Islands study area (Map 5).

AQUIFER CHARACTERISTICS

The water-yielding properties of an aquifer are a function of pore size and their interconnection. For quantitative ground-water studies, an estimate of the aquifer characteristics is required. The most common method for determining the water-yielding properties of an aquifer is by means of a pumping test. The yield of a well, as determined from a pumping test, may be used to provide information on the water-yielding properties of the materials encountered such as specific capacity. The specific capacity of a well is its yield, in Imperial gallons per minute per foot of drawdown (Igpm/ft), for a stated pumping period and rate. The specific capacity is numerically expressed as Q/s , where:

Q = pumping rate (Igpm)

s = drawdown in feet

In addition, pumping-test data may also be used to provide an estimate of the transmissivity and the hydraulic conductivity of the material in which the well is completed. The transmissivity (T) is defined as the rate of flow of water in Imperial gallons per day (IGPD) through a vertical strip of the aquifer one foot in width and extending the full saturated thickness of the aquifer under a hydraulic gradient of one foot per foot at the prevailing temperature of water.

The hydraulic conductivity (K) may be determined using the relation

$K = \frac{T}{m}$ where:

K = hydraulic conductivity (ft/day)

T = transmissivity (IGPD/ft)

m = contributing thickness of the aquifer (ft)

Specific Capacity

Statistical analyses of specific-capacity data (derived from pumping tests) by means of specific-capacity frequency graph (Figure 4) provide a convenient method of comparing the water-yielding properties of the material in the study areas.

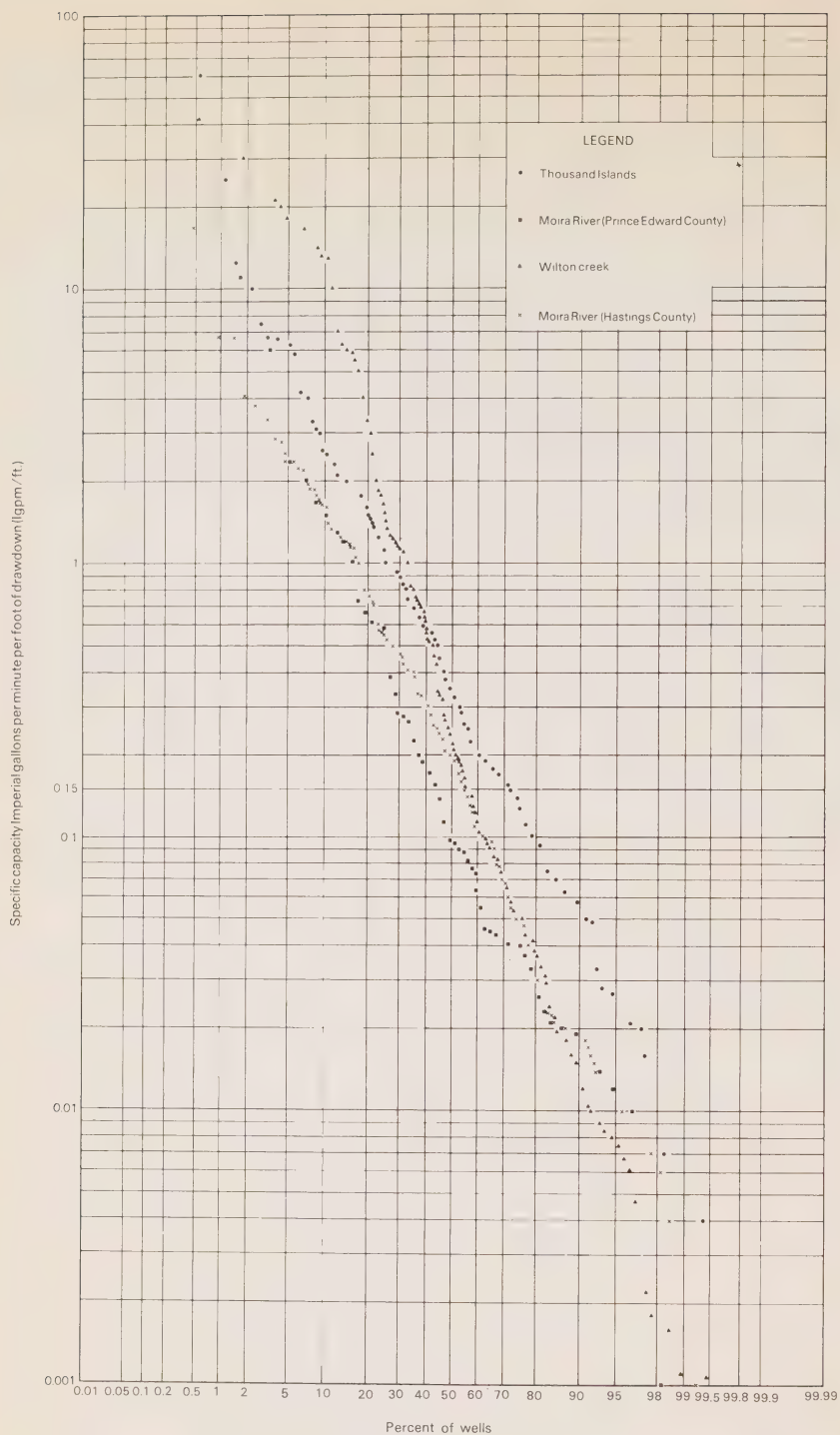


Figure 4. Specific-capacity frequency graphs for bedrock wells in the IFYGL Moira River, Wilton Creek and Thousand Islands study areas.

Insufficient data were available to compile frequency graphs on the overburden materials. The specific-capacity data for wells completed in the bedrock were tabulated in order of magnitude and the frequencies were computed by the Kimball (1946) method. Values of specific capacity were plotted against percent of wells on logarithmic probability paper. The slope of the line passing through the data points indicates the variability of the water-yielding properties of the material; steeper slopes signify greater variability than flatter slopes. Comparison of the frequency curves for the three study areas (Figure 4) indicate a similarity in slope (i.e. variability). In addition, the productivity of the wells is also similar with 50% of the bedrock wells completed in the study areas having an average specific capacity of approximately 0.20 Igpm/ft of drawdown (Figure 4).

These specific-capacity data suggest that the yield of bedrock wells in the study areas is independent of the lithology. The productivity and variability of the bedrock in the study areas appears to be the same (Figure 4), although wells in the Moira River and Wilton Creek study areas are completed in marine carbonates and claystones of Middle Ordovician age and wells in the Thousand Islands study area are completed in hard crystalline rocks of Precambrian age. This further suggests that the well yields are primarily dependent on the fracture density of the bedrock which is a result of tectonic processes to which the rocks have been subjected since their deposition. Specific-capacity data are not available in the study areas to permit a comparison with wells completed in the sandstones and arkoses of the Potsdam and Shadow Lake formations (Basal Group). Data on file with the Ministry of the Environment (Sobanski, 1970) indicate that these formations are more productive (specific-capacity of 3.5 Igpm/ft) than those comprising the bedrock surface (Simcoe Group and Precambrian) in the study areas.

Transmissivity (Modified Non-Equilibrium Well Formula)

Information from the short-term pumping test data from the water-well records on file with the Ministry of the Environment were utilized to estimate the transmissivity (and by analogy, the hydraulic conductivity of the different materials). Transmissivities were obtained using the modified non-equilibrium well formula (Cooper and Jacob, 1964):

$$T = \frac{264 Q}{\Delta s}$$

where: T = transmissivity (IGPD/ft)
 Q = pumping rate in Imperial gallons
 per minute (IGPM),
 Δs = change in drawdown per log₁₀
 cycle (feet)

The derivation of the formula is based on the following assumptions (Johnson 1966):

- 1) the water-bearing formation is uniform in character and permeability in both horizontal and vertical directions,
- 2) the formation has uniform thickness,
- 3) the formation has infinite areal extent,
- 4) the formation receives no recharge from any source,
- 5) the pumped well penetrates and receives water from the full thickness of the water-bearing formation,
- 6) the water removed from storage is discharged instantaneously with lowering the head.

The above-mentioned assumptions are not met in totality; however, it is assumed that the transmissivity values obtained from the well-record data are within an order of magnitude of the absolute values.

The results of the computations of hydraulic conductivity for the various materials in the study areas are presented in Table 6.

TABLE 6. HYDRAULIC CONDUCTIVITY (K) OF THE MATERIALS IN THE IFYGL MOIRA RIVER, WILTON CREEK AND THOUSAND ISLANDS STUDY AREAS (Data are from short-term pumping tests).

Material	Area	Number of Wells	Mean K (ft/day)	Range of K (ft/day)
Gravel, Sand & Gravel, Sand	Moira River	28	135	3-1396
	Wilton Creek	15	223	1-1271
	Thousand Islands	2	530	212- 847
	Total	45	182	1-1396
Till, Clay, Silt, etc.	Moira River	4	18	1- 42
	Wilton Creek	3	6	1- 7
	Total	7	13	1- 42
Limestone	Moira River	714	4	.002- 59
	Wilton Creek	264	5	.002- 49
Crystalline bedrock	Thousand Islands	179	2	.002- 34

Transmissivity (Specific Capacity)

The transmissivity of an aquifer can be estimated from the specific capacity of production wells. The theoretical specific capacity of a well may be written as:

$$Q/s = \frac{T}{114.6 W(u, r_{w/B})}$$

where:

$$u = \frac{2242 r_w^2 S}{Tt}$$

$$r_{w/B} = \frac{r_w}{T/P' m'}$$

$W(u, r_{w/B})$ = well function for leaky artesian aquifers (Hantush, 1966),

Q = discharge of pumped well (l/gpd),

s = drawdown (feet),

r_w = nominal radius of well (in feet),

T = transmissivity (l/gpd/ft)

S = coefficient of storage,

t = pumping period in minutes,

p' = coefficient of vertical permeability of confining beds (l/gpd/ft²),

m' = saturated thickness of confining bed (feet)

Reliable data are not available on the coefficient of storage (S) in the study areas. The magnitude of S depends on the elasticity of the aquifer material and the fluid. In confined aquifers, S does not show large variations, generally ranging from 10^{-6} to 10^{-4} (Kruseman et al, 1970). In the study areas, almost all the well records on file with the Ministry of the Environment indicate confined conditions (i.e. having a static water level above that where the water was found). According to Meyer (Bentall, 1963), any changes in the coefficient of storage (S) correspond to only small changes in the transmissivity (T) and specific capacity (Q/s); therefore, inaccuracy in estimating S is not a serious limiting factor.

With regard to the vertical permeability of the confining bed (P'), no data are available on this parameter in the study areas.

In addition to being dependent on the hydraulic properties of the aquifer and confining beds, the specific capacity (Q/s) will vary as a result of the following factors:

- 1.) r_w (the nominal radius of the well) - Q/s increases with increasing r_w , i.e. directly proportional to $\log r_w^2$,
- 2.) t (the pumping period) - Q/s decreases with increasing time, i.e. inversely proportional to $\log t$,
3. s_w (the well loss) - Q/s decreases with an increase in pumping rate in wells with a high s_w .

The relationship between the theoretical specific capacity and the transmissivity of an artesian aquifer is shown in Figure 5 (after Csallany and Walton, 1963). It is assumed that the conditions depicted in Figure 5 are applicable to the Moira River, Wilton Creek and Thousand Islands study areas. Hydraulic conductivities were computed from specific-capacity data, using Figure 5, for artesian wells (confined conditions) in the study areas and the results are presented in Table 7. According to Walton (1962) and Walton et al (1962), the transmissivity that is computed from specific-capacity data does not vary significantly between a pumping period of one to eight hours and a limited range of the nominal radius (r_w) of the well. In order to minimize errors, only wells with a pumping period ranging from one to ten hours and with a well diameter of four to eight inches were used in the computations of hydraulic conductivity from specific-capacity data (Table 7).

The data in Table 7 indicate that the hydraulic conductivities derived from the specific-capacity data are larger by approximately a factor of four to six than those hydraulic conductivities derived from the modified, non-equilibrium well formula. Sufficient data on well losses (s_w) and hydraulic properties of the confining beds are not available to delineate the hydraulic conductivity from the specific-capacity data to any greater degree of accuracy.

GROUND-WATER CONTRIBUTION TO LAKE ONTARIO

Introduction

The Darcy formula, $Q = TIL$, was used to compute the amount of direct ground-water inflow to Lake Ontario, where:

Q = quantity of water in imperial gallons per day (IGPD),
 T = transmissivity (IGPD/ft)
 I = hydraulic gradient (feet per foot),
 L = width of cross section (feet).

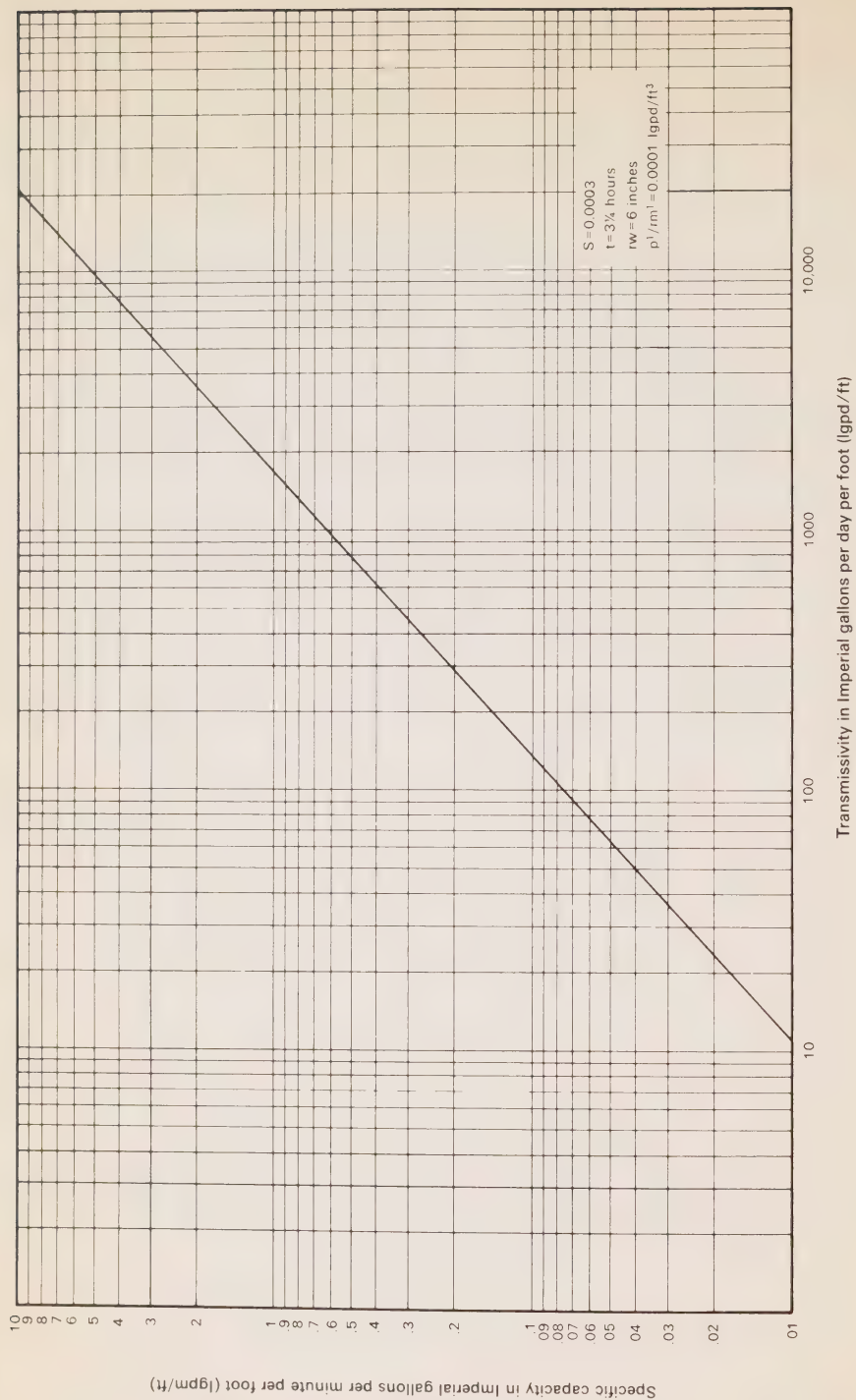


Figure 5. Theoretical relationship between specific capacity and transmissivity (after Csallany and Walton, 1963).

TABLE 7. COMPARISON OF HYDRAULIC CONDUCTIVITIES (K) DERIVED FROM SPECIFIC-CAPACITY AND PUMPING-TEST DATA OF THE SAME WELLS IN THE IFYGL MOIRA RIVER, WILTON CREEK AND THOUSAND ISLANDS STUDY AREAS.

Material	Area	Number of Wells	Mean Diameter (inches)	Mean Pumping Period (hours)	Mean K from Specific-Capacity Data (ft./day)	Mean K from the modified non-equilibrium well formula (ft./day)
Sand, Sand & Gravel, Gravel	Moirs River	20	6.14(0.58)	1.97(1.30)	589 (1295)	155 (340)
	Wilton Creek	12	6.22(0.07)	2.16(1.58)	1,035(2,794)	153 (355)
Limestone bedrock	Moirs River	209	6.22(0.51)	1.40(0.77)	23(72)	4 (10)
	Wilton Creek	143	6.18(0.14)	1.23(0.71)	36(73)	6 (10)
Crystalline rocks	Thousand Islands	176	5.88(0.67)	1.43(1.21)	14(47)	2 (5)

(294) standard deviation

In order that values be assigned for the parameters listed previously, several assumptions on the ground-water flow field in the study areas were made. The assumptions, with respect to contributing area, depth of active flow, saturated thickness, transmissivity and hydraulic gradient are discussed below.

Contributing Area

As indicated in an earlier section, the area near the Lake Ontario shore is considered to be in a zone of general ground-water discharge. In order to facilitate the computation of ground-water inflow to the Lake, it was assumed that the area within a distance of one mile from the shore was representative of the conditions in the zone of ground-water discharge.

Depth of Active Flow

The mean value of bedrock penetration for wells completed in the bedrock was found to be 32, 41 and 69 feet, respectively, for the Moira River, Wilton Creek and Thousand Islands study areas. From the above data it was assumed that significant ground-water flow in the bedrock would not extend below 50 feet of bedrock penetration in the Moira River and Wilton Creek study areas, and below 100 feet in the Thousand Islands study area. The larger figure for bedrock penetration in the Thousand Islands study area probably reflects the harder nature of the crystalline rocks and suggests that fractures extend to a greater depth in these rocks than fractures developed in a carbonate terrain. These arbitrary values of 50 and 100 feet of bedrock penetration in the study areas are considered to be the limiting boundary between the active and stagnant parts of the ground-water reservoir.

Saturated Thickness

The reported, static water level in the well records was used to determine the saturated thickness of the materials within a distance of one mile from the Lake Ontario shore in the study areas. In many wells a relatively low, static water level in conjunction with a thin overburden thickness indicated that the contribution of ground water from the overburden was negligible.

Transmissivity

Hydraulic conductivity values, derived from short-term pumping tests (Table 6) using the modified, non-equilibrium well formula (Cooper and Jacob, 1964) were used to compute the transmissivities of the materials within the zones of interest. The various materials reported in all the logs of wells within a distance of one mile from the Lake Ontario shore were assigned a hydraulic conductivity which was then multiplied by the saturated thickness to determine the overall transmissivity in the active part of the ground-water reservoir. For those wells ending in overburden an additional transmissivity for 50 feet of bedrock in the Moira River and Wilton Creek study areas, and for 100 feet of bedrock in the Thousand Islands study area was used. For the computations of the bedrock wells, it was assumed that all the wells penetrated the full thickness of the active part of the ground-water reservoir.

The total transmissivities for each well were summed and the results are presented in Table 8. It was further assumed that the transmissivity values of about 2400, 1500 and 3400 IGPD/ft (Table 8) are representative for the shore area under consideration in this hydrogeologic region.

Hydraulic Gradient

The average hydraulic gradient (I) was assumed to be 0.0065 feet per foot in the Moira River and Wilton Creek study areas and 0.0075 feet per foot in the Thousand Islands study area (Map 5) as indicated in the earlier section on ground-water movement.

Computation of Ground-Water Inflow

The values for T and I, as derived above, were substituted in the Darcy formula $Q = TIL$, to obtain a value of ground-water contribution to Lake Ontario, per mile length of shoreline as follows:

Moira River

$$\begin{aligned} Q &= TIL \\ &= 2437 \times 0.0065 \times 5280 \\ &= 83,638 \text{ IGPD per mile length (of shoreline)} \\ &= 0.155 \text{ cubic feet per second (cfs) per mile length} \end{aligned}$$

Wilton Creek

$$\begin{aligned} Q &= TIL \\ &= 1455 \times 0.0065 \times 5280 \\ &= 49,935 \text{ IGPD per mile length (of shoreline)} \\ &= 0.093 \text{ cubic feet per second (cfs) per mile length} \end{aligned}$$

Thousand Islands

$$\begin{aligned} Q &= TIL \\ &= 3385 \times 0.0075 \times 5280 \\ &= 134,046 \text{ IGPD per mile length (of shoreline)} \\ &= 0.249 \text{ cubic feet per second (cfs) per mile length} \end{aligned}$$

TABLE 8. MEAN VALUES OF TRANSMISSIVITY , DEPTH OF STATIC WATER LEVEL, OVERBURDEN THICKNESS AND BEDROCK PENETRATION FOR WELLS COMPLETED WITHIN ONE MILE OF THE LAKE ONTARIO SHORE IN THE IFYGL MOIRA RIVER, WILTON CREEK AND THOUSAND ISLANDS STUDY AREAS.

Area	Number of Wells	Mean Hydraulic Conductivity (ft/day)	Mean Transmissivity (IGPD/ft)	Mean Overburden Thickness (feet)	Mean Bedrock Penetration (feet)	Mean Static Water Level (feet below surface)
Moira River	221	4 (8)	2437(3515)	14 (11)	36 (30)	12 (9)
Wilton Creek	36	5 (10)	1455(737)	7 (7)	62 (30)	15 (10)
Thousand Islands	137	2 (4)	3385(6394)	12 (16)	83 (43)	15 (10)

(1552) standard deviation

The transmissivity values, as derived above, were used to compute the total volume of ground water discharging to Lake Ontario from the hydrogeologic region in which the Moira River, Wilton Creek and Thousand Islands are considered to be representative. This region extends eastward from the Trent River to the eastern boundary of the Lake Ontario drainage basin on the St. Lawrence River at the Town of Prescott (Figure 1). The Moira River study area is assumed to be representative of the western portion of the hydrogeologic region which extends eastward for 31 miles along the Bay of Quinte from the Trent River to the Napanee River. The Wilton Creek study area is considered to be representative of the central part of the hydrogeologic region that extends for approximately 59 miles of shoreline from the Napanee River, along the east shore of Long Reach, the north shores of Adolphus Reach, the North channel and Lake Ontario, to the Town of Gananoque on the north shore of the St. Lawrence River. The Thousand Islands study area is representative of the eastern portion of the hydrogeologic region which consists of approximately 46 miles of shoreline along the north shore of the St. Lawrence River from the Town of Gananoque to the Town of Prescott. Using the above-mentioned values, it was estimated that 4.81, 5.49 and 11.45 cfs of ground-water are discharging into Lake Ontario from the west, central and eastern portions of the hydrogeologic region, respectively. These values give a total of 21.75 cfs of ground-water discharge from the hydrogeologic region. This value of 21.75 cfs is similar to the value of 18.57 cfs for roughly the same area as computed by Haefeli (1972).

Additional Ground-Water Inflow

An additional amount of direct ground-water discharge to Lake Ontario can be computed for the shoreline in the County of Prince Edward which forms part of the Moira River study area. A total of approximately 144 miles of shoreline bordering the Bay of Quinte and Lake Ontario are present in the county. If it is assumed that the value of 0.155 cfs per mile length of shoreline in the Moira River study area is applicable to the area, an additional 22.32 cfs of ground-water discharge may be added to the previous total of 21.75 cfs. These estimates suggest that a grand total of 44.07 cfs of ground water is discharging into Lake Ontario from the eastern hydrogeologic region.

SUMMARY

A hydrogeological evaluation of the IFYGL Moira River, Wilton Creek and Thousand Islands study areas was made for the IFYGL program in order to estimate the amount of ground-water inflow to Lake Ontario. These study areas are considered to be representative of the hydrogeologic region extending from the Trent River to the eastern boundary of the Lake Ontario drainage basin at the St. Lawrence River near the Town of Prescott (Figure 1). The hydrogeology of the study areas was assessed utilizing field investigations of the geology, data from observation-well networks and information from water-well records on file with the Ministry of the Environment.

The IFYGL Moira River lies in parts of the physiographic regions of the Napanee Plain and Prince Edward Peninsula (Map 1). The physiographic regions of the Napanee Plain and the Leeds Knobs and Flats wholly enclose the IFYGL Wilton Creek and Thousand Islands study areas, respectively (Map 1). Regional topographic gradients are in the order of 33 feet per mile (0.0065 feet per foot) in the IFYGL Moira River and Wilton Creek study areas and in the order of 40 feet per mile (0.0075 feet per foot) in the IFYGL Thousand Islands study area.

The climates in the study areas are influenced by the presence of Lake Ontario and as a result are very similar. Long-term, annual meteorologic data (tables 1, 2) suggest that the climate of the hydrogeologic region is slightly wetter toward the east and that the temperature is relatively uniform in all the areas under consideration.

The bedrock in the hydrogeologic region consists of crystalline rocks of Precambrian age overlain by clastic rocks of Cambrian and Middle Ordovician age (Potsdam Formation and Shadow Lake Formation, respectively) in turn overlain by marine carbonates of Middle Ordovician age (Table 3). A veneer of glacial debris is found capping the bedrock over parts of the area but for the most part bedrock is found outcropping. Sub-surface information from water-well records on file with the Ministry of the Environment indicate that the configuration of the bedrock surface is similar to that of the land surface (Map 2). The drainage initiated on the bedrock surface appears to be coincident with the present-day drainage and seems to be controlled, for the most part, by structural features (joints, fractures, etc.) in the bedrock. The bedrock is the primary source of water for domestic and agricultural uses in the study areas under consideration.

An overall decrease in the storage of the ground-water reservoir occurred in the study areas during the Field Year period from April 1, 1972 to March 31, 1973. This is indicated by an average decrease in water levels of 0.97, 0.18 and 0.28 feet (Table 4) in the observation-well networks for the IFYGL Moira River, Wilton Creek and Thousand Islands study areas, respectively. Climatological data (Table 5) indicate that excess precipitation of 3.67, 6.47 and 5.23 inches over the long-term,

annual average occurred in the IFYGL Moira River, Wilton Creek and Thousand Islands study areas, respectively during the Field Year period. These data suggest that a decrease in precipitation over the long-term annual average will probably result in a shortage of ground-water supplies in the study areas.

The variability in the magnitude of the observation-well hydrographs from the observation-well networks in the study areas (Figure 3) suggest that a significant variation in the hydraulic properties of the bedrock is present.

Water-level data from water wells completed in different water-bearing horizons in different seasons and years suggest that the general direction of ground-water flow can be determined from these data (Map 5). Ground-water divides are generally coincident with surface-water divides indicating that ground-water movement is from topographically high to topographically low areas.

Well-productivity data suggest that the yield of bedrock wells in the study areas is independent of the lithology and primarily dependent on the fracture density of the bedrock. Wells completed in either the marine carbonates and claystone of Middle Ordovician age or crystalline rocks of Precambrian age range in specific capacity from 0.001 to 30 Igpm per foot of drawdown with an average specific capacity of approximately 0.20 Igpm per foot of drawdown (Figure 4).

In order to evaluate the quantity of ground water discharging to Lake Ontario, an estimate of the hydraulic conductivity or transmissivity of the materials through which the ground water flows is required. Hydraulic conductivities of the overburden materials and bedrock were computed using the modified, non-equilibrium well formula and also using specific-capacity data (Table 7). Hydraulic conductivities derived from specific-capacity data are larger by a factor of four to six than those hydraulic conductivities derived from the modified, non-equilibrium well formula.

The contributing thickness of bedrock to significant ground-water flow was estimated from water-well data to be 50 feet in the IFYGL Moira River and Wilton Creek study areas, and 100 feet in the IFYGL Thousand Islands study area. The latter estimate of 100 feet suggests that fractures extend to a greater depth in the harder crystalline rocks of the IFYGL Thousand Islands study area than those fractures developed in the carbonate terrain of the IFYGL Moira River and Wilton Creek study areas.

Using hydraulic conductivity values derived from short-term pumping tests, an average transmissivity of about 2400, 1500 and 3400 Igpd per foot was computed for the materials near the Lake Ontario shore in the IFYGL Moira River, Wilton Creek and Thousand Islands study areas. Ground-water inflow to Lake Ontario was estimated to be 0.155, 0.093 and 0.249 cfs per mile in these study areas, respectively, giving a total of approximately 22 cfs for the hydrogeologic region that extends eastward from the Trent River to the eastern boundary of the Lake Ontario drainage basin on the St. Lawrence River. An additional amount of direct, ground-water discharge to Lake Ontario was computed for the shoreline of Price Edward County giving a grand total of approximately 44 cfs of ground-water discharge from this hydrogeologic region.

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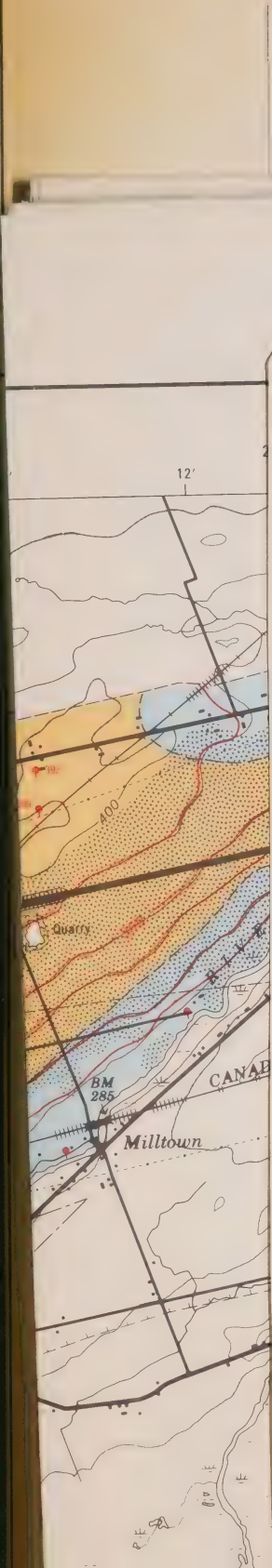
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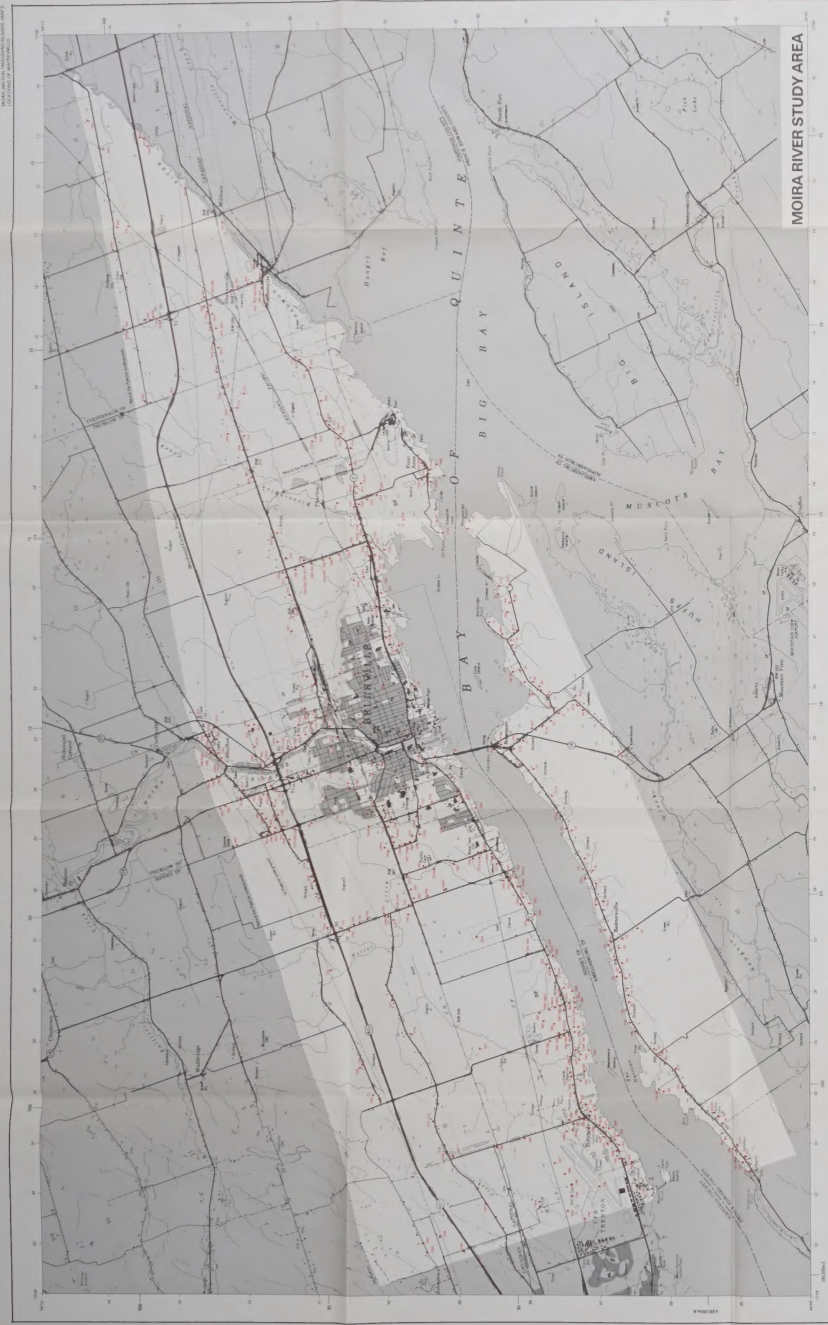
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WATER RESOURCES REPORT 5e

Maps in pocket:

- Map 1 - Physiographic Regions, Meteorological Stations and Observation Wells
- Map 2 - Bedrock Geology and Topography
- Map 3 - Locations of Water Wells
- Map 4 - Surficial Geology
- Map 5 - Generalized Potentiometric Surface



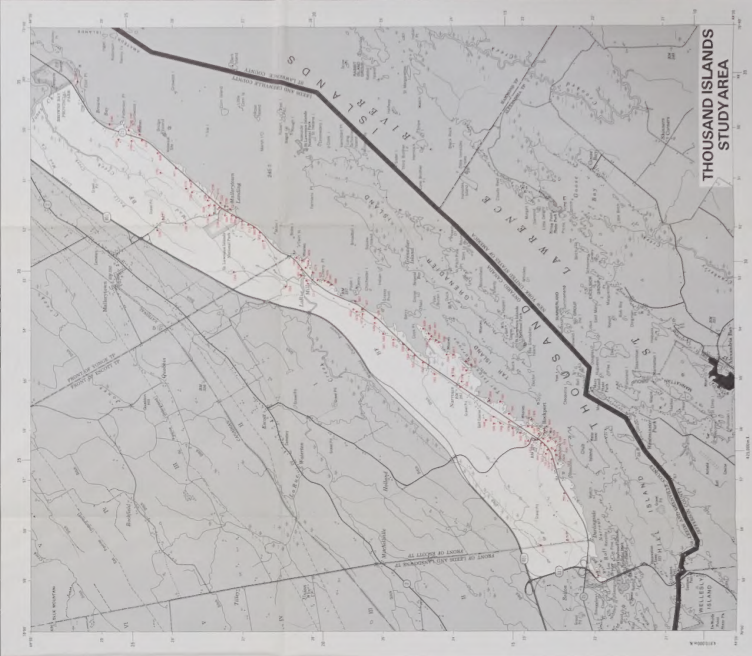
LEGEND

- International Airport
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SOURCE OF INFORMATION

Information was obtained from the following sources:

- Environment Canada (1995)
- Map data obtained from a 1:50,000 topographic map of the Wilton Creek area.
- Information from the Wilton Creek area.



MOIRA RIVER, WILTON CREEK and THOUSAND ISLANDS STUDY AREAS

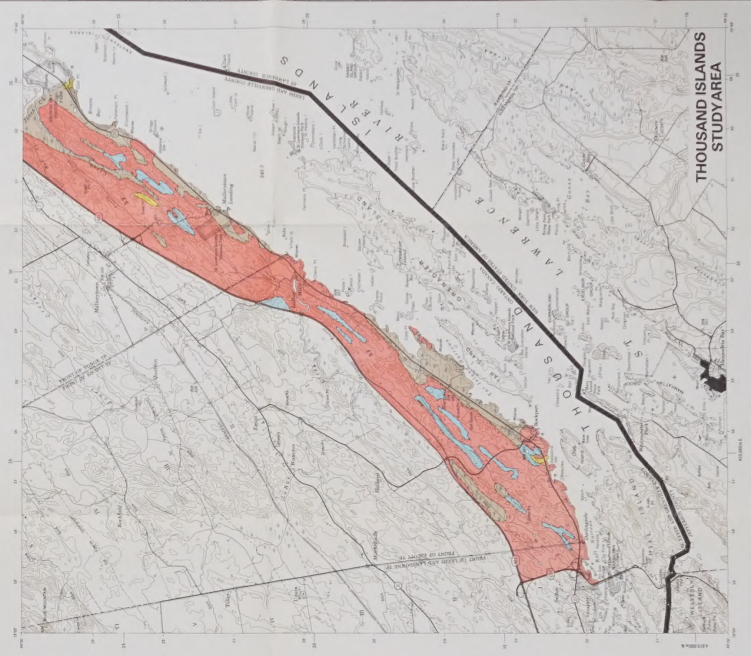
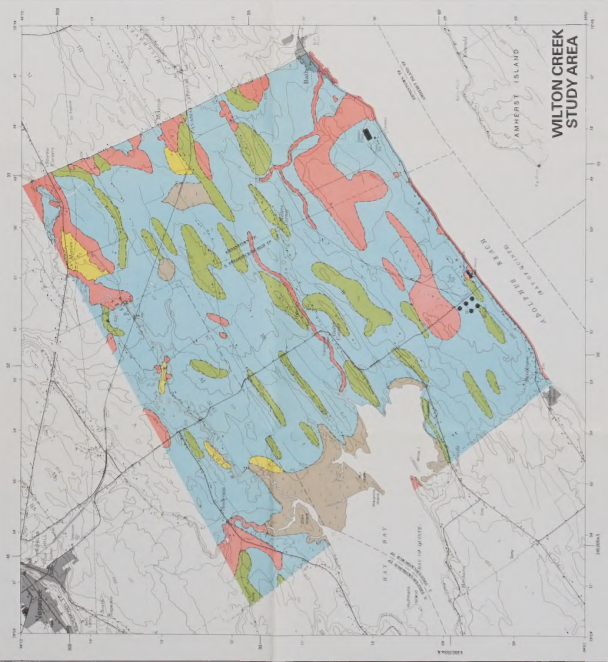
MINISTRY OF THE ENVIRONMENT
CANADA

INTERNATIONAL FIELD YEAR FOR THE GREAT LAKES

MAP 3

Scale 1:50,000

LOCATIONS OF WATER WELLS



LEGEND

1. Water bodies
 2. Land use
 3. Topography
 4. Infrastructure
 5. Other

SYMBOLS

1. Water bodies
 2. Land use
 3. Topography
 4. Infrastructure
 5. Other

NOTES OF INFORMATION

This map was prepared by the Ministry of the Environment, Government of Ontario, in cooperation with the Ministry of Natural Resources, Government of Ontario, and the Ministry of Agriculture, Food and Rural Affairs, Government of Ontario.

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MINISTRY OF THE ENVIRONMENT
 INTERNATIONAL FIELD YEAR FOR THE GREAT LAKES
MOIRA RIVER, WILTON CREEK and THOUSAND ISLANDS STUDY AREAS
 MAP 1
 SURFICIAL GEOLOGY
 Scale 1:50,000
 1 inch = 2.5 miles
 1 centimetre = 0.4 miles

